IN THE SPECIFICATION:

Please amend the numbered paragraphs of the specification as follows to correct minor errors, as kindly pointed out in the Office Action, and to clarify certain terminology.

-- [0002] The field of the invention is the fabrication of arbitrary optical micro- and nano- ~~optical~~ structures and devices as a result of the realization that integrated near-field/far-field optical imaging with on-line atomic force (AF) imaging and other scanned probe methods (SPM) can guide multistep processing of such optical elements. A crucial component in such processing is iterative theoretical simulations with constraints imposed by the near-field optical results. As used in this application, a theoretical simulation of an optical device that is to be fabricated is a mathematical model ("simulation") of the desired ("theoretical") structure of the device and of the optical fields within and outside the device. As described below in paragraph [0039], the model may be based on the well-known Helmholtz wave equation. Near and far field measurements of the characteristics and parameters of the device as it is being fabricated and iterative recalculation of the model provide accurate monitoring of the process. With such a combination of theory and near-field optical data together with SPM technology aided by new methods of highly accurate refractive index imaging, which is also a part of this invention, the order and the extent of multiple step processing can be guided to obtain optical solutions that could not be previously achieved or could not be achieved with the accuracy and the repeatability that is required by the high tolerance requirements of industry today.

- - [0003] The steps that have to be guided have previously been lenses or lenses with other waveguides or other micro- and nano-scale optical elements. These steps include either no

tapering or tapering using pulling and/or mechanical and/or laser polishing and/or heating, with [[and/]] or without etching and/or writing and/or masking with or without imposed radiation and with or without photoresist and/or other similar procedures and/or imprinting and/or molding and/or deposition depending on the parameters of the micro- [[and]] or nano-optical structure that has to be achieved. - -

- - [0004] The synergistic interconnection between theory, where paraxial/far-field approximations fail, the near-field optical characterization and associated SPM methodology, and the integrated production methodologies are an essential component of this ~~patent~~ invention. As a result, arbitrary structures can be generated for waveguides, such as a glass fiber or a micropipette or a crystal fiber or other materials that act as a waveguide, or other structures that can be achieved for micro- and nano- optical objectives by controlled manipulation, molding or deposition of materials to concentrate or focus light. - -

- - [0005] The goal of such manipulation is a variety of applications from optical communications, microscopy, sensing, and other applications of such integral lensed systems or other light concentrating or focusing devices that could not be achieved without the essential steps of this invention. Thus, these waveguide or other structures can act as stand-alone elements or be included as part of a complex of components to achieve solutions in microscopy, scanning, and in other areas, that are not achievable otherwise, and ~~these inventions~~ the devices that have resulted from these new and highly accurate optical elements are also part of this ~~patent~~ invention. - -

- - [0011] The prior art fails in several directions. First, it was impossible to guide a multi step process of micro-or nano-optical element formation to achieve the type of elements with the accuracy and repeatability that is required today. The prior art relied on one or another of the processes noted above but has never been able to effectively mesh these technologies to achieve the ultimate micro- and nano-optical solutions that are desired. In addition, the prior art has not recognized the crucial role of near-field optics together with other scanned probe methods and high resolution refractive index methods in guiding the theoretical simulations for micro- and nano-optical elements when far-field/paraxial approximations fail. Thus, from both a point of view of guiding the theory and the fabrication and from the point of view of characterizing the resulting elements, near-field optics plays a central role in this ~~patent~~ invention, and the prior art has not realized the importance of this technique in such optical element fabrication. Even with such simulations, there was no method of characterizing such lens fibers that made measurements in the regimes that the theoretical simulations required. - -

- - [0012] The invention can be summarized as follows:

1. The crucial nature of near-field optics and SPM technology in guiding, in an interative way, the theoretical simulation and the fabrication without reliance on paraxial/far-field optics;
2. The ability to iterate and apply [[as a]] the result of [[1]] multiple processing methods that have never been previously integrated;
3. The ability, as a result of 1 and 2, to produce micro- and nano- optical elements that could either not be produced previously or could not be produced with the accuracy and the repeatability that can be achieved as a result of this invention; and [[.]]

4. The ability, as a result of 1, 2 and 3, to produce new optical devices that were impossible to achieve before the ability to form such micro- and nano-optical elements. - -

- - [0018] Figure 5A illustrates the parameters that can ~~beadjusted~~ be adjusted to produce, with high accuracy, protrusions that are important in further steps of integral lens formation. - -

- - [0022] Figure 7 illustrates deep ultraviolet laser stripping that allows [[fo]] highly accurate coating of the stripped fiber. - -

- - [0025] Figure 10 illustrates a ~~nanindentation~~ nanoindentation as a way to form defined structures on ~~coating~~ coatings that are placed on fibers and other optical components. Dotted horizontal line (10.1) is placed just above the center of the nanoindentation as a guide. - -

- - [0026] Figure 11 illustrates two structures, 11.1 and 11.2, that are solid immersion [[lens]] lenses that were formed by the procedures outlined in this ~~patent~~ invention. - -

- - [0030] Figure 15 illustrates a nanoparticle grown on the tip of a structure by the procedures [[of]] described in this ~~patent~~ application that can have the ability to have atomic [[foce]] force sensitivity. - -

- - [0032] Figure 17 illustrates a line-scan of the NOSM image in the focal [[plan]] plane of the single mode lensed fiber. - -

- - [0033] Figure 18 illustrates a miniaturized ~~prove~~ probe fiber [[-]] device under test in a characterization system [[base]] based on the principles of the characterization methods described in this ~~patent~~ application. - -

- - [0035] The present invention ~~describes an~~ is directed to Optical Element Fabrication. A new theoretical understanding of the parameters that are important in fiber optical element, including fiber lens, production is the first inventive step of the ~~patent~~ present invention. - -

- - [0037] In one emulation of our method, not to exclude others, we consider a fiber lens with a hyperbolic shape (Figure 1) which is a geometric result that can be achieved optimally only by a combination of multiple production methods that are a part of this ~~patent~~ invention. For this geometrical model of the tapered fiber lens, three spatial regions are considered: the core (1.1), the cladding (1.2) and air (1.3). The core has a conical shape with the angle determined by the taper angle (1.4) and the core to cladding diameter ratio. The interface between cladding and air is considered to have a hyperbolic shape. This shape is described by two parameters: the asymptotic angle and the radius of curvature (1.5) at the height of the hyperbola. The asymptotic angle is assumed to be the same as the taper angle (1.4). - -

- - [0039] To realize the criticality of the calculation as the first step in the formation of the optical elements described in this ~~patent~~ application, we will focus, as an example, on the field inside and outside a fiber lens. This was obtained by numerical solution of the wave (Helmholtz) equation with boundary conditions that were defined and *adjusted* using an iterative procedure in which the near-field optical measurements and the technologies associated with near-field optical

measurements were used to *adjust* these boundary conditions so that exact replication of simulation and results were obtained. Such iteration and adjustment is novel. - -

- - [0045] Near-field optical measurements allow us to practically confirm the theoretical predictions and help define the boundary conditions of the calculation. This is shown on the graph in Figure 4 in which the theoretically predicted waist diameter is confirmed by such near-field optical measurements. Thus, an essential component in the theoretical developments are the hand in hand characterization of the near-field optical measurements associated with specifically designed fiber lens fabrication methods as highlighted in this section. The same is also the case with all such simulations, fabrication and near-field optical characterization of the elements described in the present patent application that [[have]] has resulted from this invention.- -

- - [0046] Thus, in conclusion, an inventive step of ~~this patent~~ the present invention is that the methodology of theoretical simulations with adjusted boundary conditions iteratively defined by near-field optics and its associated measurement techniques allows for:

1. The availability of exact field calculations as an effective method for design of fiber lenses and other optical elements in which the general far-field optical approximations partially or completely fail.
2. Near field and associated measurement of the field emerged from the fiber lens as the only reliable method for its characterization [[and]] since the generally used far-field characterization methodologies are not valid for the components described in this ~~patent~~ application. - -

- - [0048] The technology that is invented here allows for a synergistic integrated interaction with what has been considered to be competing technologies in fiber lens formation or have never been used in fiber/waveguide lens formation. These technologies can be listed as without or with tapering using pulling and/or mechanical and/or laser polishing and/or heating, with [[and/]] or without etching and/or writing and/or masking with or without imposed radiation and imprinting, depending on the parameters of the micro- and or nano-optical structure that has to be achieved, to produce a coordinated interplay of parameters that have not been achievable till now. In spite of the need to use all or part of these methodologies to the appropriate extent and in an appropriate order to produce the type of micro- and nano-optical elements that are needed, the difficulty of integrating these diverse technologies into a synergistic whole rested on the inability to accurately characterize the results of the integration both in terms of topography and light distribution in the near-field. - -

- - [0049] ~~As an introduction to this section~~ It is realized that, together with what has been described above for theoretical simulation, the application of an integrated characterization tool is a critical part of the process which allows for highly accurate geometric and light profiling of the micro- and/or nano- optical structure at the surface, in the near-field or at specific distances above the micro- and/or nano-optical structure with little contribution from out-of-focus light so that the phase properties of the wavefront can accurately be characterized in a way that is totally integrated with atomic force topographic and scanned probe methods (SPM) for micro- and or nano-scopic characterization including nano- and micro-heat sensing and/or with light wave measurements such as return loss, polarization dependent loss, coupling efficiency and other

similar parameters and that these methods are also totally integrated with far-field optical characterization including high resolution refractive index imaging. This integration of the simulation, production and characterization is a realization that near-field optics within this context of integrated characterization, simulation and production is the critical missing link that facilitates such multistep procedures for micro- and nano-optical element production. - -

- - [0051] It is true that measuring phase properties with a lens has been accomplished using an algorithm which is based on the transport intensity equation [A. Barty, K. A. Nugent, D. Paganin and A. Roberts, Optics Letters 23, 1 (1998)]. For this equation one needs to know the intensity in the object plane for different z sections. Measuring this intensity by means of a near-field optical probe has advantages even over such indirect lens-based methods. Since with a near-field optical probe the information that is collected has none of the distortions that occur when optical data is transformed by the optical system, which in the case of Barty [[etal]] et al is a lens. This includes the fact that, as noted above, the near-field optical technique obtains the intensity information not only without lens based distortions but also without any out-of-focus contribution. Therefore, near-field optical methodology of the light distribution in one or more optical planes is a true measure of the intensity at different z sections. In addition, with such a methodology one can consider combining the near-field optical information at certain points with the lens based information to obtain rapid analysis of the phase properties at resolutions much better than can be obtained with lens based techniques for refractive index, phase ~~distrbution~~ distribution and other phase based properties. Also such a combination can obtain the information much faster than near-field optical techniques alone. - -

- - [0053] In another emulation of such a combination, the near-field optical device is used to provide a stable source of light for the point spread function (PSF) of the far-field optical imaging system which can be based on confocal DIC or DIC with CCD imaging. Such knowledge of the PSF is crucial to the high accuracy of the index of refraction that is needed for the full characterization of some of the devices that are part of this patent. In addition, the PSF can be obtained with the device under test in place and this has never been possible previously. The device under test contributes significantly to the PSF and can alter the PSF at different locations in the sample so multiple measurements of the PSF at different locations on the sample may be needed for full theoretical analysis of the results by the theoretical procedures described above. In addition, it is realized that glass-pulling technology or other technologies allow for the production of unique point sources that can add singular information on the optical properties of the far-field microscope, especially for DIC. One such structure, not to exclude other structures, is the ability to produce a near-field optical element with two tapered fibers in order to deliver to the microscope two beams of controlled polarization and known shear vector. This allows for a true DIC PSF and is important for [[the]] achieving the highest accuracy in index of refraction measurements. All of this is possible since such glass structures or other silicon processing methods allow for these near-field element-based points of light to be present on the optical axis without obstruction from the integral atomic force cantilever that keeps the point of light with extremely high stability relative to the sample being investigated by atomic force feedback. - -

.

- - [0055] In addition to DIC one can also use a conventional far-field imaging system with or without DIC or with [and/]or without non-linear optical phenomena such as, for example,

second harmonic generation, and simply block at certain controlled positions the rays of light reaching a detector in transmission or reflection mode and this information, together with the exact 3D position from the atomic force sensor, can be used as a constraint with the calculations above to deconvolve high resolution image of the device under test. This approach also can be used effectively with difference techniques where the blocking is used together with differences in intensity when the probe is generally transparent but has a nanometric or larger opaque particle at its tip that either blocks or does not block the rays of the far-field imaging system from the position on the sample. This can be done transiently, for example, in intermittent contact or some other similar mode with the data collected at two positions in contact and at some distance from the surface. This will allow for difference spectra to be generated ~~gererated~~. Obviously, the data can also be collected at multiple positions of the particle from the surface. These ideas can be extended to any techniques that use far-field optical imaging, for example confocal Raman microspectroscopy. In some cases these methodologies can be combined with evanescent wave illumination instead of the conventional illumination that is present in all far-field optical microscopes. In all cases the use of an atomic force sensor, directly correlated pixel for pixel with the optical imaging, allows a very strict delineation of the surface of the sample and this is a powerful constraint for the theoretical calculations. - -

- - [0062] One emulation of this invention (not to exclude other emulations), is when the tapering of the fiber is done under laser heating with defined tension and defined cooling. For achieving the characteristics needed for this goal the heat has to be kept at a minimum while the tension is kept at a maximum with a cooling that has to be optimally controlled based on the results of the near-field optical characterization and its associated methodologies and the iterative

theoretical simulations. The pulling gives a specific angle of taper to the fiber tip. The control of this waist diameter to a level of ± 0.25 microns depends on the exact characteristics of the taper, and this needs to be accurately simulated and characterized together with the waist diameter of the beam; [[and]] these parameters can be measured by including near-field optics and its associated techniques in this loop of iteration. It was not realized previously that such a closed loop had to be a critical part of the process of lens formation, which had to maintain Gaussian characteristics. In fact before this ~~patent~~ invention integral lens fiber makers publicly indicated the need to develop characterization tools. - -

- - [0063] In addition, with such closed loop control we have realized that the spot size is not only related to the cone angle but is also related to the separation between the end of the fiber and the position to which the core extends. With the control that we can now exercise we can modulate the geometry and the nature of the laser-heating phase at the tip after the tapering with tension, heating and cooling discussed above. In one emulation, not to exclude others, we have accomplished reproducible coupling efficiencies of >80% for a variety of lens parameters with such fine control. - -

- - [0064] In another ~~emualtion~~ emulation of this invention (Figure 5 A), not to exclude other emulations, it was realized that for fiber lens production there was great importance to the protrusion that can be produced as a result of the pulling with tension, heating and cooling discussed above. The defined protrusion in the center of the fiber (5.1) has to be controlled, depending on the parameters of the lens as characterized by the techniques discussed above. The protrusion allows us to control the centration and this has never before been discovered as a

parameter of crucial importance in such fiber lens formation. This protrusion is subsequently removed to defined distances with controlled etching as defined by the characterization. For example 30 minutes is needed to produce a geometry that modulates the curvature (5.2) of the protrusion as seen in Figure 5B. Subsequent laser or other melting (see Figure 5C) is used to achieve the final parameters of the lens (5.3) as defined by the near-field optical results. - -

- - [0069] In addition, it is possible to use a combination of the techniques described above to achieve tapering with polishing and lensing at ninety degrees to the fiber axis or with appropriate coating to produce a beam splitter by coating a mechanical and laser polished lens on one face only or producing an elliptical structure on one side of a polished lens. - -

- - [0072] In this case the lens made by the above procedure is subsequently polished from two sides, [[(180^{0})]] 180° from one another, and then another laser step is introduced to smooth the rough polished surface to achieve the control and optical quality that is desired. With such a combined procedure it is possible to achieve a ratio of the elliptical axes of at least 1:3. This is another emulation of these combinations but does not exclude other combinations. - -

- - [0074] Also, the deposition of metals on the stripped fiber for soldering and other requirements including magnetic attraction can be achieved with high accuracy relative to such fiber lenses, both in terms of vacuum deposition and electrochemical and electroless depositions, if the criticality of the characterization described above is applied in a closed loop to such fiber lens metallization. These depositions can be used to achieve hermetic seals to various packaging by combination with electrochemical deposition and the galvana plastic deposition of materials

such that the material is deposited in a plastic form. They can also be used to achieve 3D depositions of the fiber by soft lithography techniques or controlled vacuum techniques with rotation together with the lensing procedures ~~invented in this patent~~ described in this application. The resulting structures can also be laser welded. - -

- - [0075] All of the procedures described in this ~~patent~~ application can also be used [[to]] for other waveguide structures, including those that can be microfabricated with silicon by the alteration in the refractive index of silicon by doping or other means. - -

- - [0077] First, the process of nanoindentation (Figure 10) can be used to create a nanodimension opening (10.1) at the tip of the structure of the fiber or the side of a fiber that is polished at an angle at the end or at any point that is desired. In one emulation of this procedure the resulting structures can be controlled in terms of their optical output in an iterative way if the structure of the fiber aperture achieved is complexed with the light input and output both in terms of intensity and/or distribution. This will permit automation of such aperture formation using either nanoindentation procedures or other procedures that could produce nano openings and these include focused ion beam, chemical etching etc. Also, a femtosecond laser can be used to produce a nanodimension opening using non-linear ablation. Also, a process of laser or heat assisted nanoindentation is possible in which a device makes the nanoimpression and a laser or other device is used to transiently ~~metlt~~ melt the surface in which the indentation is to be created. Also, the metal depositions can completely cover the lensed or the unlensed fiber tip or waveguides so that an aperture or apertures can be formed on these structures by coating the device fully with metal and then dipping the fiber tip in a solution that will deposit a resin or

other viscous solution on the surface such that at the lens, because of its angles and interactions, is not coated with the viscous solution. ~~and so~~ Accordingly, a small region of the metal coating can be exposed and etched, allowing for the coating to be in close proximity to the lens and preventing subsequent problems such as vibrations and other mechanical or similar problems. - -

- - [0079] The approach described ~~in the~~ above, in which accurate simulations are combined with unique integrated characterization are also critical to the fabrication of these and other components that can achieve lensing and/or waveguiding including mode convertors, multi lens arrays and other solutions such as microelecromechanical approaches and silicon waveguides in which dopants are used to create waveguides in silicon substrates or femtosecond lasers are used to alter index of refraction in a variety of materials. All these lensing or waveguiding solutions will not be able to achieve their desired results without the integration of the simulations and the characterization that are part of this invention. Only with such simulation and characterization can accurate parameters be defined and no previous invention has realized the criticality of such a closed loop of theoretical simulation, characterization methodologies and diverse production technologies including materials that require standard microelectronic and microelectromechanical fabrication in order to produce defined lensing and/or waveguiding structures that are in glass and/or other materials with a variety of geometries including materials that require standard microelectronic and microelectromechanical fabrication. - -

- - [0083] In addition to the above, the techniques of deep UV lithography, with [[and]] or without projection techniques, as used in the semiconductor industry ~~and these~~ can be used to form a pattern onto the fiber tip that can alter the index of refraction or topography in a parallel

fashion. This aspect of the invention can not only provide for focusing but can also provide for dispersion compensation and multifocal and other characteristics such as phase front correction, removal or imposition of birefringence or removal of various aberrations in the resulting lenses.--

- - [0084] Again, the iterative simulation and characterization tools described in this patent application are essential for achieving these parameters. - -

- - [0086] The above procedures allow for any optical parameter that is allowed by Fresnel or diffraction theory or other theories to be achieved. An example is a cylindrical lens with two axes having the same foci. Also, as noted above, the invention is [[also]] not limited to uv laser radiation and other lasers can also be used such as ultrafast laser ablation and and/or index of refraction alteration by linear and multiphoton processes. Furthermore, as noted above, laser or other methods of heat or other assisted [[and/]] or unassisted nanoindentation can be used to reproduce diffractive or Fresnel structures by such assisted nanoimpressions. - -

- - [0088] All of these unique lenses can be combined, as with all the lenses above, either with [[and]] or without Bragg gratings written into the fiber in the path of the fiber before the lens. The variety of procedures that the simulation and characterization of this invention allow ~~permit~~ permits the selection and order of the methodologies in order to combine a lens with a fiber Bragg grating without erasing the grating. - -

- - [0090] In addition, the processes described above can produce a solid immersion lens with high index fibers. In such a procedure, before or after tapering a ball can be formed at the

end of the fiber by laser melting and the ball can be subsequently polished by a combination of mechanical and laser polishing to produce a flat mushroom head that can act as a solid immersion lens. The ability to combine mechanical and laser polishing is crucial here since the surface of the polished surface has to be made optically of good quality with laser polishing. Once again, an essential component is for the solid immersion lens to be simulated and characterized by the characterization tools described above without which the characteristics of the lens cannot be effectively achieved. - -

- - [0091] In one emulation such a lens (11.1) can also be placed at the end of a cantilevered fiber (Figure 11) to provide the additional sensitivity of an integral atomic force sensor so that the solid immersion lens can be brought in contact with, or can closely approach, a surface and also to sensitively align this lens relative to the illuminating microscope objective. In another emulation, not to exclude other emulations, such solid immersion lenses can be made with various polishing combinations, as described in this ~~patent~~ application, so that it could have other geometries such that the flat surface can be polished to a tip and coatings can be applied if so desired. These lenses can also be combined with Fresnel and diffractive lens characteristics. - -

- - [0093] In ~~additon~~ addition, the methods described in this ~~patent~~ application in which the essential components of simulation and near-field and associated characterization are used to guide the fabrication as described above, can produce a lensed fiber in which the spot size at the focus is the same as the core diameter at a distance of [[upto]] up to 50 microns. - -

- - [0094] Such ball lenses can be used as one such lens or multiple such lenses. For example, in one emulation, not to exclude others, an integral fiber lens can be integrated with a ball lens to get a collimated beam of light that can then be used with a second ball lens or regular lens to get a very small diffraction limited spot size. Such combinations can also allow [[for a]] the working distance of an integral fiber lens to be extended. For such extension of the working distance from the fiber lens it is possible to get small spot sizes far away by, in one emulation not to exclude others, ~~to have~~ having an integral fiber lens, one ball lens for creating a parallel beam and then another ball lens with an aperture, to obtain the highest resolution at the longest distance away from this second ball lens. - -

- - [0095] In addition, the procedures described in this patent application that include tapering and etching allow for structures in polarization maintaining fibers that permit [[for]] multiple pronged structures (see Figure 14) which can be used either uncoated or metal coated. In the case where coating is placed on these structures, the structures can be used as electrical tweezers so long as the coating is produced on each of the multiple pronged structures in a way that the isolation between the metal coated structures is preserved. - -

- - [0098] In addition, other emulations include various combinations of illumination, heat, etc., during nanoparticle formation at the tip of these structures, and these can alter the characteristics of the particle and [[is]] are also an important part of the invention. - -

- - [0100] Finally, such hollow tapered pipettes or other such devices in materials[[,]] that are not glass and that are cantilevered or not cantilevered, can be used to produce apertured

waveguides by molding. In such an emulation, a tapered micropipette or other similar hollow device is coated with a metal or an opaque substance for the optical radiation that is being used. The hollow cavity is then filled with a liquid that will form into the shape of the hollow region. This liquid can be a melt or a solution that will turn into a plastic or any other material that will have similar qualities, i.e. a liquid that will harden into the structure of the hollow region. If the material that will harden will have after hardening a larger index of refraction it will act as a waveguide and the light will be confined by the opaque material surrounding the tapered pipette or hollow cavity. Obviously the simulation and the near-field optical and other characterization techniques described herein are crucial in defining the structure, the refractive index and the light modulating properties of such devices. - -

- - [0101] Similarly, tapered or untapered pipettes or other hollow devices could be filled with such hardening materials and with controlled pressure and controlled wetting the extent that the liquid will exit the opening can be controlled. If the exit of the hollow device filled with the liquid is then placed on a mold, the exiting liquid will fill the mold and harden to form an optical element. Obviously, multiple such hollow tubes and multiple such molds can be used to automate making multiple ~~device~~ devices and/or to make multiple device arrays. ~~Obviously~~ Further, the essential characterization component of this ~~patent~~ invention can be used to characterize micro- and nano- lens arrays which are made with or without molds or with or without hollow tubes to make an individual micro- or nano- optical device or arrays of such devices, and these characterization techniques are crucial for making such devices that previously were difficult ~~or unable~~ to achieve, or could not be achieved, with the accuracy that is needed in today's industry. - -

- - [0102] In another emulation, the amount of liquid exiting can be controlled to the extent of nanometric dimensions and then coated with metal, to make, in one emulation, at the tip of, say, a force sensing device a nanometric dielectric ball covered by a metallic coating to adjust the plasmon resonance to the wavelength of the laser being employed. - -

- - [0109] The interesting question here is what happens with the rest of the modes in the tapered multimode fiber. One can think that the higher modes will ~~reflects~~ reflect back in the tapered region of the fiber or its energy will diffuse to the cladding region. - -

- - [0117] A preferred embodiment of this invention is that the probe fiber is not glued to the tuning fork but rather the tuning fork and the probe fiber are both held in piezoelectric devices that can bring the probe fiber and the tuning in close proximity to one another until the tuning senses the probe fiber. Then as the probe fiber is slightly modulated in close proximity to the tuning fork it approaches the device under test. When it gets in close proximity to the device under the test the tuning responds to the change and the feedback loop is engaged to keep the probe fiber with greater stability ([[upto]] up to 0.002 dB) relative to the device under test. Under this condition, near-field optical profiling, light wave measurements for return loss, etc., (which, as part of this invention, are also very important for monitoring the nature of the optical surfaces produced in the optical elements that are generated) and other parameters both near and far-field, including topography, can be measured without pigtailing. In essence, the invention has demonstrated that the atomic force sensing acts as an electronic glue to keep the device and the probe steady with respect to one another. The device allows for stability, repeatability and

reproducibility with [[upto]] up to 0.002 dB. The device also allows [[for]] on-line viewing of the probe and device under test with an optical imaging system (not shown in Figure 17). - -

- - [0118] Also, in another emulation, not to exclude other emulations, the device that measures the position of the probe fiber can be a lensed fiber itself as described in this ~~patent~~ application or two lensed fibers as can be produced by pulling fibers in a two channel micropipette by the procedures ~~in this patent~~ described herein. With either one lensed fiber or with two lensed fibers, or with one or two ~~or one fiber~~ fibers without lenses, the probe fiber position can be accurately measured as it approaches a surface. This is accomplished by sending light through these devices onto the probe fiber and then measuring the reflected or the transmitted light so that [[as]] the probe fiber frequency, amplitude and/or position changes as it approaches the sample. The probe fiber and the detecting and illuminating fiber can be either glued together at the appropriate position or held with piezo devices at a defined position. - -

- - [0119] The essential invention in this and other devices is the realization that today the worlds of nanopositioning, light wave measurements, and imaging are separate worlds and this invention integrates and brings these worlds together. Also, [[as]] a part of this invention is the realization that these devices that ~~affect~~ effect such an integration allow for on line tests and measurements of the type described in this ~~patent~~ application as an important part of the manufacturing process in which one device is connected to another device with appropriate means. In this vein it is important to realize that other emulations will allow for three column devices in which one device and two fibers could be handled in one system. - -

- - [0120] All of the procedures described above are easily amenable to automatic fabrication. This invention includes a complete automated system that includes each of the steps or combinations of steps, from the theory of simulation of fiber lenses that is included in a program of a computer controlling the automated process to the characterization as described in this patent application, and to the complex fiber handling, including pick-up, etc., tapering under tension, and heat, etching, controlled lensing of protrusions, mechanical polishing, laser scribing, etc., including all the steps described in this patent application. - -

- - [0121] These procedures can also include the components of this invention that include laser and other methods of index of refraction alteration and other procedures described in this patent application. - -

- - [0122] However, the critical components in the process of the present invention are the simulation and characterization methodologies described in this patent application. These allow, in an interative fashion, the production of the optical elements described in this patent application in an automatic fashion. They work even more efficiently in an automated machine based on these principles since the iteration reaches its ultimate efficiency. In addition, an automatic machine also blends very effectively with making multiple lenses on a fiber bundle. - -

- - [0123] One of the results of the optical elements that can be achieved by the inventions ~~of this patent~~ described in this application are extremely small spot size lenses that are integral with optical fibers. As noted above, diffraction limited spot sizes can be achieved. This means that in the visible region of the spectrum this can be as small as 0.5 microns. In addition, as

noted above in paragraph [0060], for example, ~~in section 5.2.A.1.c~~ these structures can be cantilevered. This means that ~~theyP~~ they could fit neatly under the lens of a microscope. With such a lensed fiber or straight lensed fiber that can now be made by the simulation and characterization techniques[[,]] that are part of the ~~inventive step of this patent~~ methods described in the present application, we have invented a simple scanning integral lensed fiber based confocal (SILC) microscope. This uses the same piezo technology that was described ~~in section 5,12~~ above. Such a device would readily replace complicated beam scanning confocal microscopes with much higher throughput, collection efficiency and resolution than conventional confocal beam scanners. The latter arises from the fact that the integral fiber lens is scanned. This means that all aberrations except spherical aberration [[is]] are eliminated. Usually only sample scanning can achieve such resolution. In addition, lens fiber bundles could increase the scanning speed by orders of magnitude. This would be similar to Nipkow disc scanning without the problems [[o]] of the Nipkow disc. The optical path in such a SLIC microscope would be that the light would be passed through the fiber and collected by the same fiber and then put either through a fiber splitter or a dichroic filter. This would also include returning fluorescent light. The lensed fiber could be cantilevered if it is to be slipped under the lens of an upright microscope or it [[can]] could be placed on an inverted microscope or placed opposite from the lens of an upright microscope. - -

- - [0124] An alternate emulation would be to place a fiber (19.1) with or without a lens in a piezo tube scanner or other device capable of scanning a fiber (19.2) for scanning, and this combination [[is]] would be placed in a port of a microscope or similar device. The tube lens of a microscope or a ball lens (19.3) as described ~~in section 5.7~~ above would make a parallel beam

(19.4)<u>,</u> and then the objective lens of a microscope or another ball lens (19.5) [[will]] <u>would</u> create a spot on the sample (19.6). - -

- - [0125] In one emulation, the piezo tube scanner could scan the beam and the lens of the microscope [[can]] <u>would</u> cause a focused spot. Such a combination could form a diffraction limited spot on the sample and the lens could collect the light with high efficiency and send it back through the fiber through which the illumination was accomplished. A fiber splitter could separate the excitation and the detection. In addition, the channels of illumination and detection could also be separate. ~~With the~~ <u>The</u> illumination <u>would be</u> through the fiber and the detection through another channel which can be attached to another optical path in the microscope<u>.</u> ~~which~~ <u>The</u> <u>microscope</u> can have a large area detector including a charge coupled device for detection. In the case of the detector being a charge coupled device<u>,</u> the scan of the fiber [[can]] <u>would</u> be adjusted to fall on a different pixel of the charge coupled device and the software for reading the charge coupled device [[is]] <u>would be</u> adjusted to register the fiber position with the pixel of the device or some other software or hardware arrangement that permits knowing the pixel being illuminated. Also<u>,</u> multiple fibers can be scanned [[also]] to get more parallel illumination. - -

- - [0126] Such a system that creates a diffraction limited spot is important not only for the highest resolution and/or super-resolution beam scanning confocal microscopy with the highest throughput but, also in terms of the invention described ~~in 5.2.A.1b~~ <u>above</u>, of blocking the radiation with an opaque particle, such high resolution confocal imaging is essential. In this later case it is better to scan the sample while keeping the fiber illuminator [[here]] fixed. Alternately, one can scan the particle in concert with the fiber beam scanner described ~~in this section~~ <u>above</u>.

Thus, the combination of these two inventions of very high resolution, very high ~~througput~~ throughput confocal microscopy with radiation blocking for imaging allows for new instrumentation and new resolution barriers to be crossed in optical imaging. Obviously, the blocking by a particle can be done in intermittent contact mode so that data can be collected at different positions of the probe with respect to the surface, and difference images can be generated from the collected data. It is also possible that the particle can be scanned in unison with the fiber. It is also possible to use multiple fibers and multiple or particles. Also, in another emulation the particle can be a particle that enhances rather than obscures the signal, and this would occur if the particle had a plasmon resonance at the frequency of illumination. - -

- - [0128] The technique described ~~in this section~~ above can be very effectively applied to data storage applications including magnetic storage in read only or read and write systems with and without the use of opaque or enhancing particles. In one emulation of magnetic optical storage, writing of bits can be modulated with a nanometrically controlled opaque particle that can be raised from the surface for heating directly with the illumination or illuminated with higher intensity while the particle is on the surface to transfer heat to the surface for writing. The position of the particle can be modulated either by varying the speed in flying head technology or some other active or passive feedback technique with the particle position adjusted either for writing or for high resolution reading. Also, other emulations can be conceived with the particle being an enhancing particle with a plasmon resonance at the frequency of illumination. - -

- - [0129] The high resolution provided by lensed fibers based on the inventive steps [[of]] described in this ~~patent~~ application also has implications for other light scanning devices such as

scanners for printers, copiers, etc. For such applications the invention considers also lensed fiber bundles that could also be of use in such light scanning devices. - -

- - [0130] The developments described in this patent application [[of]] for integral lensed fibers with and without cantilevers and the diffraction limited performance that these lenses can achieve, can give very high resolution spot sizes, with these spot sizes being even smaller at shorter wavelengths. In addition, these micro lenses [[are]] not only have inherent minimal aberration because of their size but also are produced with such high quality because of the simulation, the characterization, and the multi-step methodologies that are a critical part of this ~~patent~~ invention. In addition, these geometries of cantilevered fibers with such high quality integral lenses form very good elements for presently available flying head technology in data storage devices. Thus, passive feedback can raise the integral lens fiber that can be made with a short focal distance. Obviously, as described in this ~~patent~~ application, a fiber based solid immersion lens can be made with the very light properties of a fiber, and again this could be ~~complexed to~~ combined with the flying head technology of data storage which could keep the solid immersion lens in the near-field. - -

- - [0131] The devices described in this patent application can also be coated with multiple layers of metal isolated with layers of a dielectric such as silicon dioxide with contacts of the metal layers at the lens of the device. Such devices can act also as optical and thermal sensing devices and such devices can be made with force constants that will allow either in their cantilevered or straight form for the devices to act as atomic force sensors for measuring topography and other scanned probe microscopy parameters such as electrical properties. - -

- - [0133] In addition, there are other cases where such multiple coatings can produce at the tip of such optical fiber and other similar elements, light detecting and producing structures. In addition, other devices, not to exclude other emulations, can include a tapered or other device with multiple metal and separating dielectric coatings, so that as the device, which is flexible, bends, [[and]] the resistance of the material between the metal coatings will change. Such devices have the potential to approach surfaces with feedback based on the alterations in the resistance or other electrical parameter and can also act as a thermal resistor and also could have optical properties as noted above. - -